Slope Stability Radar A Need for Open Pit Mines Stability

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Abstract— Slope stability radar is a relatively new technology and is improving the way mines manage and minimize the risks associated with slope instability, enabling the appropriate precautionary measures to be taken. This technology meets the requirements that a monitoring system should have regarding precision, area coverage and failure mode detection. It is reliable in a variety of conditions, operates in a safe mode not requiring personnel to work on or near instability, and does not obstruct mining operations. The radar is equipped with a wireless link which transmits data in real time so engineers can make immediate decisions without having to be near a potentially unstable slope and the radar is trailer mounted for easy relocation. A variety of displays for data interpretation are available including deformation maps, digital photographs for reference and plots of deformation over time of specific points on the wall face. Alarm thresholds can be set, and are based upon total deformation and deformation of an area over a time frame.

Key words: Open Pit Mines Stability, Slope Stability Radar

I. Introduction

Slope stability is a major issue in open pit mining. Effectively measuring the stability of slopes can ensure continued production. Accurately predicting when a failure will occur can lead to appropriate decisions being made on mining in an area with suspect wall conditions, or revising mine plans to ensure continued production. Data on slope stability has traditionally been collected through the use of deformation measurements. Surveying equipment such as robotic remote total stations and wire extensometers are typical. Although these means of measurement are adequate, the potential to maintain safe pit walls or to safely increase the steepness of pit walls with this equipment is difficult to achieve. Having steeper walls will increase the profitability of the operation, but must be accomplished in a safe matter as the results of failure can be catastrophic.

Slope stability radar has addressed some of the inadequacy of the older systems of measuring slope stability. Using radar technology the resolution and precision of measurements taken has remained competitive with current survey equipment, but has provided a more continuous and quicker approach to taking these readings and using the data to make more informed decisions on whether a pit wall is safe for mining operations to take place. This paper summarizes and researches the technology involved in using radar to monitor the stability of pit walls and how this technology is improving open pit mining. The specific improvements to data acquisition and the prediction of slope failures when compared to older more traditional methods of measuring slope stability will be discussed. The benefits to mining by using this technology can be seen through safer mining practices based on advance detection of pending failures in addition to the continuity of mine production through a better understanding of rock movements.

II. Requirements of slope stability analysis

A. Monitoring Requirements

There are a few important requirements of any measuring tool used to determine whether open pit walls are moving and whether there movement will lead to failure. The instrumentation involved in monitoring slope stability should have sufficient coverage of any unstable area. Monitoring displays should allow the detection of more than one failure mode whether it is wedge, circular, toppling, plane or rock mass failure. The deformation or wall movement should be measured precisely enough to give meaningful results. If the measurements are imprecise then an accurate picture of what failure modes may develop in the pit wall or slope in question will not be achieved.

The acceptable level of accuracy needed for adequate slope monitoring should be 10 mm at the very least, and 0.1 mm would be advantageous. Mines today prefer to have movement and deformation monitored to the millimeter (Noon, 2003). Instrumentation should also be able to be moved easily and not delay or obstruct mining operations so as to keep production on schedule. Slope monitoring instruments are designed to aid in achieving the best possible production by knowing how and when to mine certain benches and not prevent equipment from accessing areas planned for mining. In addition, the relaying of false information that may cause an area to be quarantined must be avoided. Data interpretation and analysis should be relatively simple for operators to use and produce an accurate risk assessment.

B. Data Acquisition

Data acquisition should be speedy and data should be relayed in real time to prevent unexpected movements in wall slopes or benches to go unnoticed. The equipment should also be able to be used continuously in any situation, including taking readings through any type of weather, night or day, in addition to being able to obtain clear data through dust and smoke which are common often present in open pit mining operations. Lastly, the monitoring device should be able to conduct its task in an economically viable manner in terms of purchasing and operating cost.

III. Signs of Instability

A. Visual Indicators

There are signs that usually indicate whether a bench or wall slope may be experiencing some instability. Cracks may form on the berm or bench floor or on the face of a wall that require investigation. Other signs that a wall may be progressing towards failure is the increase in rock spoils that may fall from the face of the wall filling the berms.

B. Benefits Of Precision Equipment

The signs may be clear that a failure is imminent in the near future but the progression towards failure must be measured.

A typical question is "On which day is the wall to fail if at all?" The answer has been somewhat elusive in open pit mining but the science of monitoring slope stability has made strides to better document the progression towards failure which has led to more accurate predictions of when and how the slope of a bench face may fail. The reality is that large failures can be well predicted, but small life threatening failures are not usually predictable (Blackwell & Calder, 1979). Monitoring slope stability correctly is vital to prevent risk to life and equipment while not hindering production as a result of over cautious decisions.

IV. Slope Stability Radar Technology

A. *Failure Mode Recognition*

Like survey monitoring, the method does not indicate what is occurring inside the pit wall, only on visible faces. The mode in which a wall slope will fail has to be interpreted from surface (face) deformation, and this is usually possible (Blackwell & Calder, 1980) including estimation of strike and dip of continuities and properties of the interface. However the conventional means of monitoring slope stability activity using these earlier methods is dependent on the density and continued functioning of such as cube corner survey reflectors and wire lines. There are many ways that a slope may fail dependent on the local geology as well as the forces that may be released with mining activities. In fact most measurements taken that predict an inevitable failure begin months before the actual slope is in any danger of failing. These measurements are based on the downward and outward movement of material, the movement directions and the manner in which it accelerates. By knowing the characteristics of movement of a wall face, especially whether that movement is accelerating, an informed decision can be made on the failure mechanism and when the failure will occur. Failures are usually documented to aid in the prediction of how slopes behave in the local geological and rock property conditions. This will also aid in wall slope design and in utilizing appropriate support and stabilizing methods.

B. *Radar Technology*

Slope stability radar is a product of advanced technology for surveys of the earth from space for defence purposes. Synthetic aperture radar was successfully applied via satellite to monitor glacier movement in the mid 1990's, and there were probably defence information gathering satellites in use earlier. This new development in radar technology paved the way for other applications including land based (terrestrial) applications. The major difference in the radar technology employed for slope stability monitoring is the type of aperture being used. Aperture is defined as the cone angle that comes into focus in an image plane. The type of aperture used in satellite glacier monitoring used a synthetic aperture combining sequential returning pulses bouncing off the glaciers. The combination of these pulses produces the effect of a large antenna creating an accurate depiction of the terrain (SAR Interferometry, n.d.). As the satellite is continually moving, such complexity is essential. Since slope stability uses an immobile instrument and relatively stationary target it is able to use real-aperture radar instead of a synthetic aperture. Using this type of aperture, precursory movements can be captured on a smaller area and a more concentrated scale.

C. *Procedures Adopted*

For the best results the instrument is located from 50 to 450 metres back from the area in which it will scan for stability as seen in Figure 1, although the range in which measurement can be confidently taken reported to be 850m.

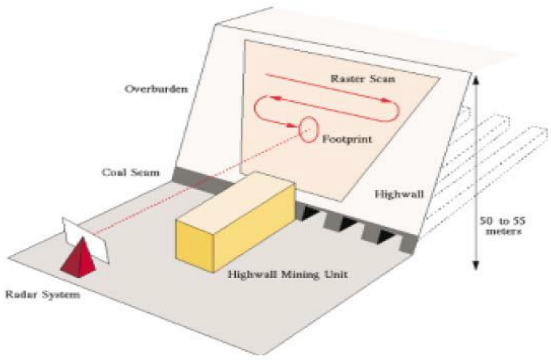

Fig. 1: Scan Pattern used by Slope Stability Radar (Noon, 2003)

Figure 1 shows slope stability radar scanning wall at a coal mine. The system of data collection begins with a preliminary scan to reference when determining movement and stability. A series of digital images are taken creating a mosaic of photographs showing the entire area that the radar is able to scan. This enables the user to have a visual representation of the slope from which a two-dimensional scan area can be analyzed. These scans usually take approximately 15 to 30 minutes depending on the size of the area. Each scan contains phase information on a per pixel basis that can be compared to the first scan and the scan previous to it. Once the comparison is made, measurements can be deciphered through measuring the difference between the phases of two different scans. The actual resolution of the raw data is of such low quality as to exclude the achievement of a precise depiction of sub millimeter movement. Phase information from signals or pulses is used in a process called differential interferometry which enables the much better resolution needed for millimeter and sub millimeter movements to be recorded and estimated with confidence.

Differential interferometry employs phase values from two radar scans targeting the same area producing an interferogram. The interferogram is then subtracted from an earlier or original scan to measure any displacement that might have taken place. So by taking the phase value of a single radar return and comparing the information with phase information from a different scan on the same target, an accurate depiction of the slope activity can be achieved (Taser, 2003). A single scan is too complicated to provide any meaningful data, however, with an additional scan for comparison, displacements and movement can be captured. The phase information used to measure deformation is conducted on a per pixel basis.

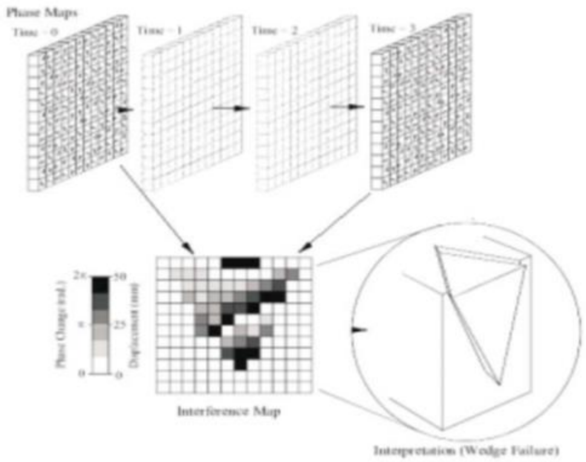

Fig. 2: Failure Mode Interpretation through Multiple Scans (Noon, 2003)

This means that each pixel in the output is responsible for a corresponding area on the wall face. Therefore the average movement over the area in which a pixel is representative is shown on a per pixel basis. As the distance from the wall face to the instrument increases so does the area each pixel is represents and hence the resolution decreases and a less accurate picture of deformation will result. Each scan has the ability to move approximately 320 degrees in the horizontal direction and 120 degrees vertically. An image that captures deformation can be produced and the failure mode can also be determined by analyzing the nature of the movement on the slope face as shown in Figure 2.

V. Components of Slope Stability Radar

The ease in which slope stability radar can be used is another great asset of the technology. It is trailer mounted which makes moving locations easy and less set up time is required once deployed. It is self-powered having a remote power supply consisting of a battery power supply and a diesel-powered generator. With this ability the radar is able to take measurements twenty-four hours a day regardless of weather conditions. With these components, the slope stability radar acts as an independent machine requiring little influence from mine personnel.

The radar disk is mounted on a dual axis platform capable of moving in two dimensions. This dish is available in 0.92m and 1.8m diameters. The 0.92m version has a maximum range of 850m and the 1.8m has a range of double the smaller model. A camera is installed next to the dish to provide a visual representation of the wall face being monitored. Along with the electronics and computer module components of the system, a display and interface module is mounted on a swivel allowing personnel in the area to keep current remotely with slope activity. The slope stability radar equipment is designed to tolerate vibrations and can operate under all weather conditions. A labeled diagram displaying the components is shown in Figure 3.

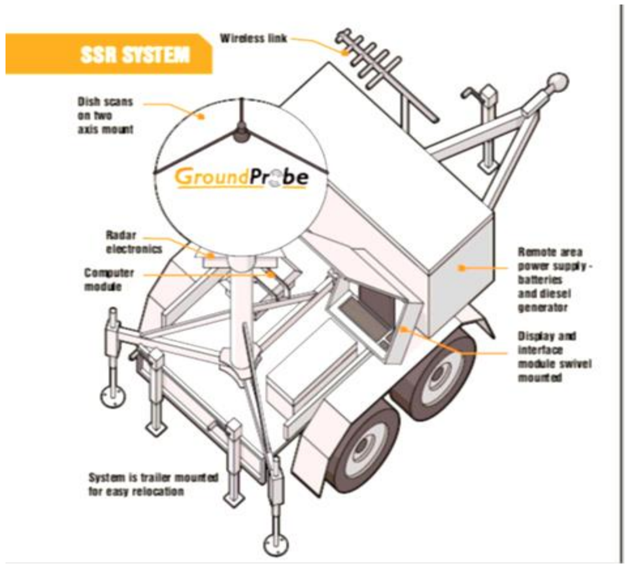

Fig. 3: GroundProbes® Slope Stability Radar (SSR Brochure, n.d.)

VI. Differences between Traditional Slope Monitoring Techniques

Some of the improvements that this system of data collection has over more traditional methods lie in the ease in which walls can be monitored and the continuous nature of data acquisition. The traditional methods, unless real time radio robotic, require more manpower and are more labour intensive. With total station surveys, reflective markers or prisms must be strategically placed at certain points along wall slopes so readings of horizontal and vertical angles and inclined distance can be taken. Not only is setting up these prisms time consuming, it may be dangerous and the prisms can be damaged, or displaced such that they no longer face the survey instrument, leading to inadequate coverage and inaccurate conclusions. This method of obtaining data is also limited to the point in which the reflective markers are located, possibly adjacent to and not in the failing material. With slope stability radar, the gathering of data is not only instant but requires no mounted prisms (unless the user wishes for whatever reason). With no mounted reflectors, mine operations has no need to worry about damaging equipment designed to relay information on movement. A further advantage of using radar technology is the picture of an entire area that is produced. Using prisms with a total station can only produce data that is exclusive to a single point where the marker is located, albeit for many points, whereas using slope stability radar data an entire wall face can be interpreted. When analyzing an entire face, a more accurate understanding of how and why a bench or wall may be failing can be achieved compared to single point analysis. A failure between two points where measurements are recorded could not be foreseen using the traditional surveying as no data would have been recorded in that area. Atmospheric anomalies temperature inversions, smoke, rain, dust and other airborne contaminants may prevent traditional instruments from taking accurate readings if at all because of the reliance on visual contact. Radar has the ability to penetrate through the smoke and dust that is so commonly produce through mining in an open pit environment, making it superior in terms of taking measurements in most situations.

VII. Benefits to Mining

Using slope stability radar has benefits in risk management. When effectively used the risk to equipment and personnel can be efficiently managed in addition to maintaining full production. Advance detection of impending failure leads to the appropriate removal of personnel and equipment minimizing risk and allowing for mining operations to proceed with confidence. Mining engineers can also make more informed risk management decisions with the aid of the slope stability radar. This not only leads to safer mining practices but also maintains production. The utilization of equipment can also be improved in areas that have been deemed as at geotechnical risk. Data is transferred in real time enabling production engineers to be more confident of decisions made. This leads to continued productivity in areas otherwise considered unsafe without an accurate real time monitoring system.

An extensive period of rainfall would increase hydrostatic pressure in the pit wall and lead to areas of a mine being shut down in anticipation of problems. Instead of shutting down these areas because of the impact of heavy rainfall, they can be closely monitored with radar. The radar enables continuous monitoring which can capture the ground movements in response to the rainfall.

All of the benefits to open pit mining discussed will ultimately lead to better mine design and increased pit life as each expansion pushback learns the lessons from the previous pit. Engineers can now confidently mine areas because they have the equipment to monitor in real time. Furthermore, data obtained by slope stability radar will aid in the understanding of rock mass movement and an understanding of the structural integrity of wall slopes in open pit mines.

VIII. Disadvantages of Slope Stability Radar

Slope stability as captured by radar does not have the best accuracy when recording large deformations, however, when recording small movements it does so on a scale that allows for meaningful results within the tens of millimeters.
Therefore when recording large deformations with precision another means of measuring would be preferred, e.g. real time radio robotic total station surveys or wire extensometers which are capable of measuring +/- 1 mm and 0.003 mm respectively. Deep seated movement cannot always be accurately recorded as radar relies on the deformation of visible surface material to acquire data.

IX. Conclusions

In open pit mining, ground movements and deformations over time are inevitable. The amount and rate at which walls move or deform is dependent on the local geology, rock and discontinuity properties, mining methods and designs of the slopes. The ability of mines to manage and minimize risks associated with wall failures can lead to safer operations as well as increased profits. When proper monitoring is implemented at an operation the nature of ground movements and the understanding of failure mechanisms can be better documented leading to more informed decisions with respect to slope stability for future push-backs and other mines.

The precision, continuous nature of collecting data in real time, and the ability to recognize different failure modes offered by radar slope stability enables informed decisions to be made. Having this system installed at an open pit mine allows for more aggressive slope design while preserving a safe working environment for personnel. Slope stability radar also provides a more complete picture of movement when faced with a slope deemed hazardous by another means of monitoring. Through a better understanding of rock slope movement, more appropriate decision regarding production and mine planning can be made. The cost of implementing this system is usually far outweighed by the extra revenue that a mine can generate. This extra revenue is provided from safely steepening slopes, extending the life of a pit, as well as saving on the costs of damaged equipment lost hours and injury to personnel. Therefore, from an economic standpoint, using slope stability radar in conjunction with other forms of monitoring is essential as it enables the maximum possible exploitation of a mineral deposit

References

[1] Blackwell G., Keast M.& Pow D. (1975). “Slope Monitoring at Brenda Mines”, 59-60.
[2] Blackwell G.H., Calder P.N. (1980) “Investigation of a complex rock slope displacement at Brenda mines. Canadians in Mining Magazine”, 73-76.
[3] Cahill, J., & Lee M. (2005). “Ground control at Lienster Nickel operations. The South African Institute of Mining and Metallurgy International Symposium of Stability of Rock Slopes in Open Pit Mining and Civil Engineering”, 322-330.
[4] “GroundProbe (n.d.). GroundProbe Precision measurements using slope stability radar and ground penetrating radar technology”. Retrieved March 29, 2007, from http://www.groundprobe.com/
[5] Noon D. A. (2003). Slope stability radar for monitoring mine walls. Mine Risk Management Conference, 1-10.
[6] Reutech Radar Systems (Pty) Ltd. (n.d.). Reutech Radar Systems (Pty) Ltd-World leaders in radar technology. Retrieved March 28, 2007, from http://www.rrs.co.za/
[7] SARS Interferometry and Surface Change Detection. (n.d.) Retrieved February 27, 2007, from http://southport.jpl.nasa.gov/scienceapps/dixon/report7.html
[8] SSR Brochure [Image] (n.d.). Retrieved March 10, 2007,from http://www.groundprobe.com/docs/ssr/SS%20Brochure%20(English).pdf
[9] Taser D. J. (2003). Simulation of a slope stability radar for opencast mining. Msc. Eng Thesis. University of Cape Town. Retrieved February 13, 2007, 6-9.